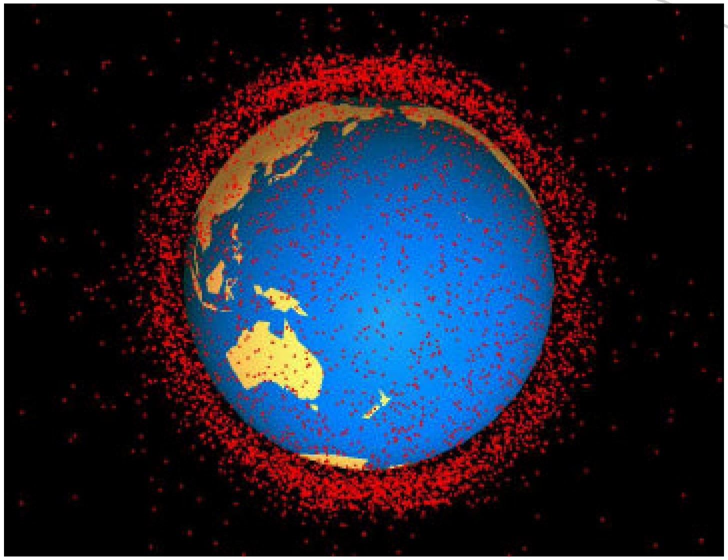
Center for Orbital and Reentry Debris Studies

CORDS

EELV/GPS IIF Orbital Debris Stu

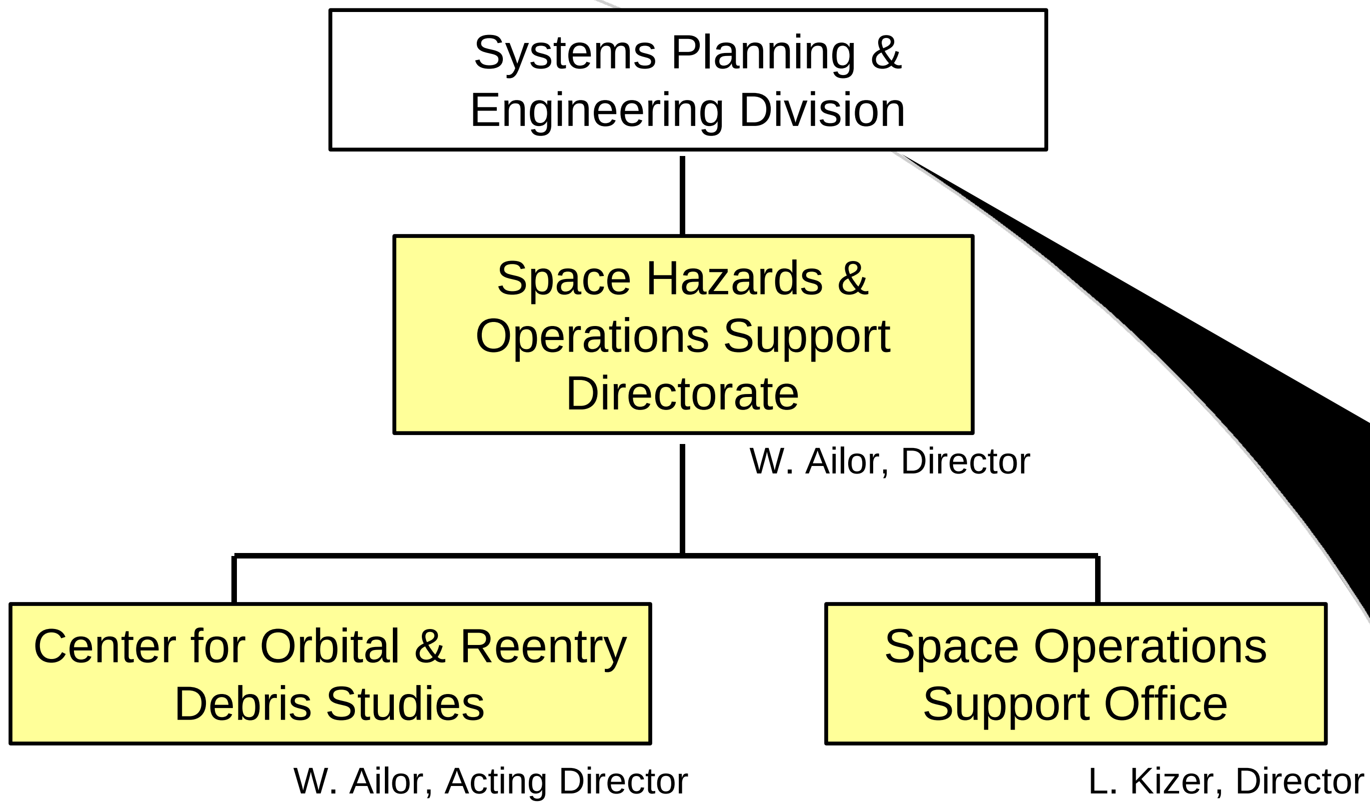
CORDS Overview



- CORDS established in 1997 to focus Aerospace research and program support in space debris, space hazards, reentry breakup
  - Space poli[illegible]port
  - Orbital risk a[illegible]
    - collision proba[illegible]
    - collision avoidan[illegible]
    - laser impingement[illegible] frequency interfere[illegible]
  - Space object reentry[illegible]
    - breakup modeling
    - hazard analysis

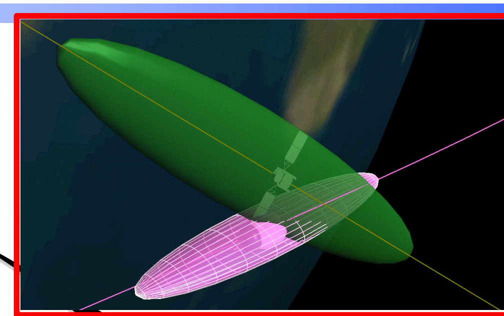
THE AEROSPACE CORPORATION

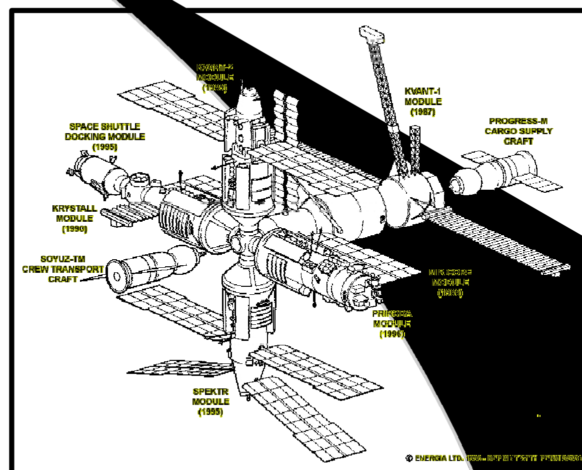
Organization



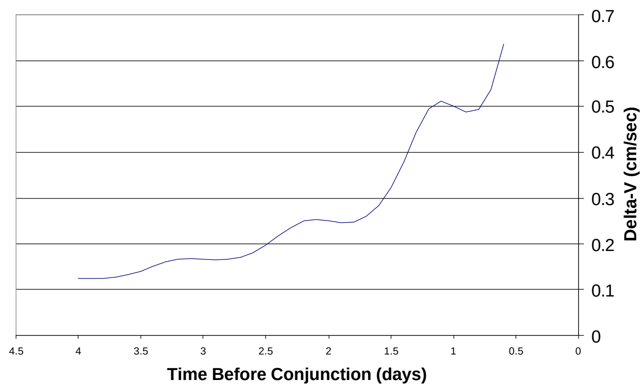
CORDS Activities

- Space Operations Support
  - COLA
- Reentry Breakup
  - Mir
- Research Projects





Sample Δ-V to Reach Threshold Probability (1E-4)



THE AEROSPACE CORPORATION

Study Objective

- Determine how EELV can best comply with EELV Operational Requirements Document (ORD) for GPS IIF, which were derived from US Government debris mitigation guidelines
  - *ORD - "EELV shall comply with national, DoD [illegible] USSPACECOM orbital debris minimization polic[illegible] minimize orbital debris after launch consistent with [illegible] objectives and cost effectiveness*
  - *As an objective, orbital debris will be de-orbited to burn [illegible] in the atmosphere.*
  - *Components abandoned in orbit shall be placed in orbits that minimize the probability of their collision with other objects."*

Study Scope

- Initial study will be limited to DoD/Government payload missions, classified missions may be covered in a subsequent study.
- Both EELV launch vehicle providers will be reviewed for missions that are required to be dual compatible.
- Initial mission analysis - GPS IIF

Direct Injection

- GPS IIA&R currently are placed in transfer orbits (100 x 10,998 nmi)with apogee kick motors part of the the SV
  - low perigee of third stage promotes a quick reentry ~2-6 yrs
  - apogee kick motor is boosted to a disposal orbit with the SV at end of mission
- GPS IIF will be directly injected into a near operational orbit (10,998 x 10,998 nmi, i=55 deg) by higher performance EELV's
  - no apogee kick motor on the satellite
  - disposal problem for the upper stage which is near GPS operational orbit altitude
- Action to dispose of EELV upper stages needed to comply with US Government debris mitigation guidelines and EELV ORD and GPS unique requirements

Focus Issues

- EELV performance for post mission disposal
- Disposal Orbit Stability
- Orbital Collision Probability

CORDS Study Team

- David Homco - EELV Program Office Coordinator
- Russ Patera - CORDS - Technical lead
- Manny Landa, Rey Urbano and Greg Furumoto -Space Architecture Department
  - EELV performance for post mission disposal
- George Chao and Anne Gick - Astrodynamics Department
  - GPS disposal orbit stability and sensitivity study
- Allen Jenkin and Anne Gick - Astrodynamics Department
  - Collision risk analysis
- Jim Gidney and Bill Emanuelsen - Consultants

EELV Performance Study

- Simulated and optimized launch ascent for each vehicle and variant as required
  - Used current definition of vehicle and performance characteristics provided by contractors
  - Included flight constraints - IIP, max Q, etc.
  - Accounted for flight performance reserves [illegible] equivalent
  - Found vehicle or vehicle variants for each con[illegible] that could perform the mission and have sufficie[illegible] reserves for post mission disposal

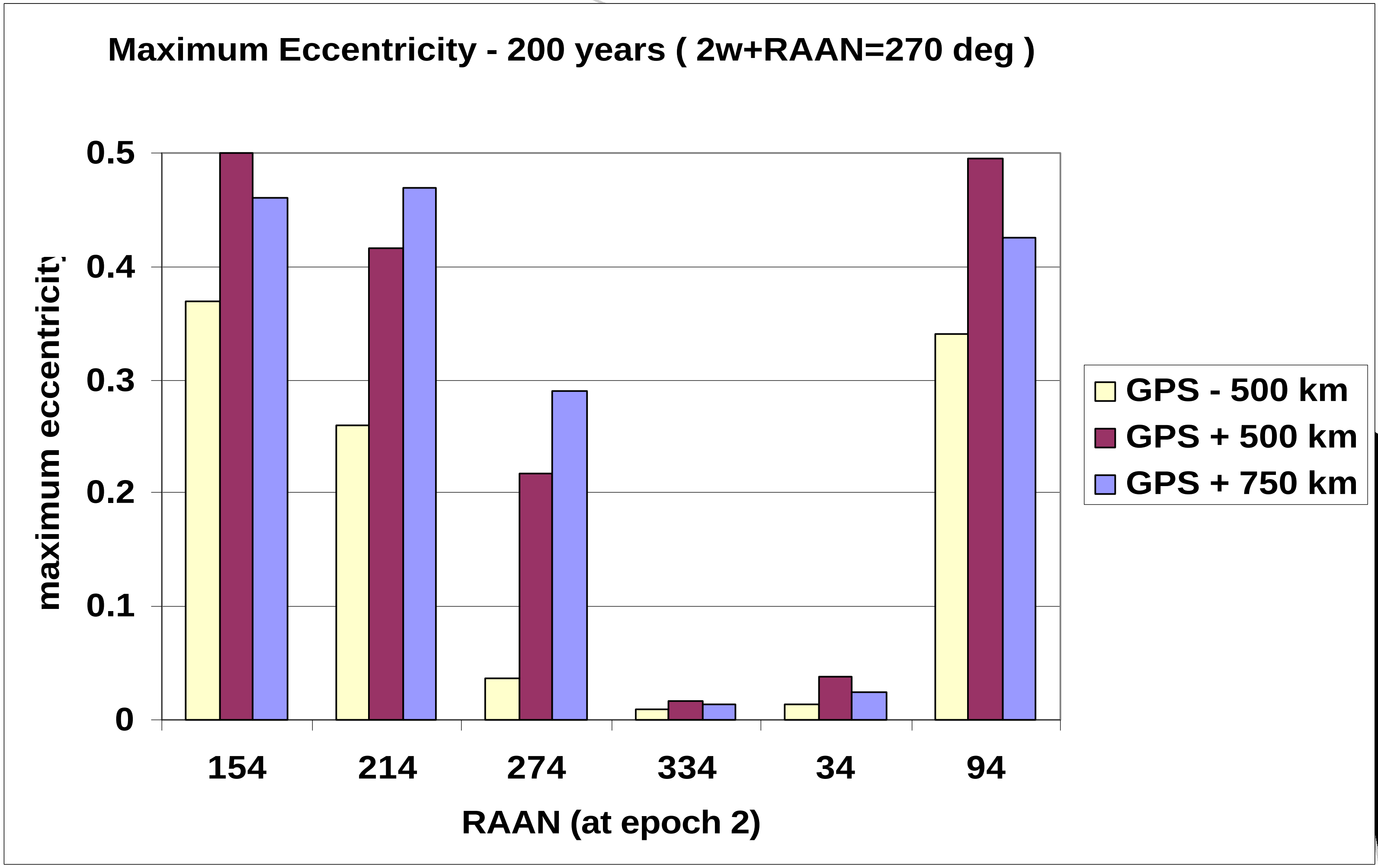
EELV Performance Findings

- Identified disposal orbit injection issues
  - Controlled reentry not feasible - altitude too high
  - A minimum of two burns required for Hohmann transfer to disposal orbit above GPS operational orbit-associated issues for engine restarts
    - minimum propellant and burn time constrai
    - propellant required for engine chill down
  - Battery life needs to account for additional time required to reach disposal orbit
  - Battery should to be discharged at end of mission
  - Disposal orbit injection accuracy an issue for long te orbit stability - perigee and eccentricity requirements
  - Strategy needed to deplete propellants while ensuring disposal orbit injection accuracy

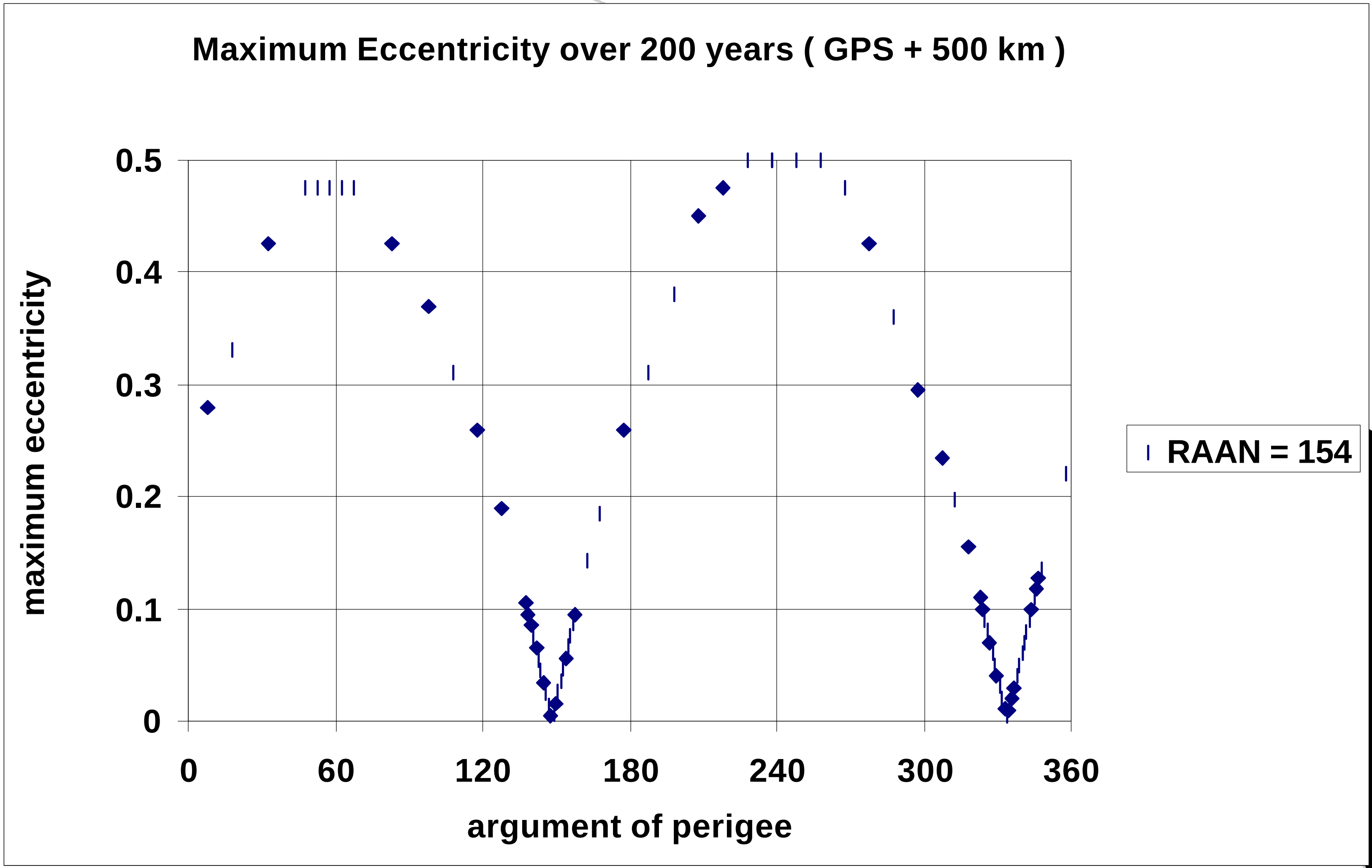
GPS Disposal Orbit Stability Study

- Sun / moon gravitational perturbations cause the eccentricity to be unstable over the long term ~20 yrs
- Disposal orbit eccentricity growth causes the intrusion of stored satellites into the operational altitude range
- Minimization of eccentricity growth is desirable to prevent disposed satellites from interfering with the operational constellation
  - Eccentricity growth depends on right ascension of ascending node, argument of perigee and initial eccentricity
  - Two values of argument of perigee minimize eccentricity growth for each GPS orbit plane
  - Initial eccentricity should be made as small as possible to minimize eccentricity growth

Sensitivity to Disposal Altitude



Sensitivity to Argument of Perigee



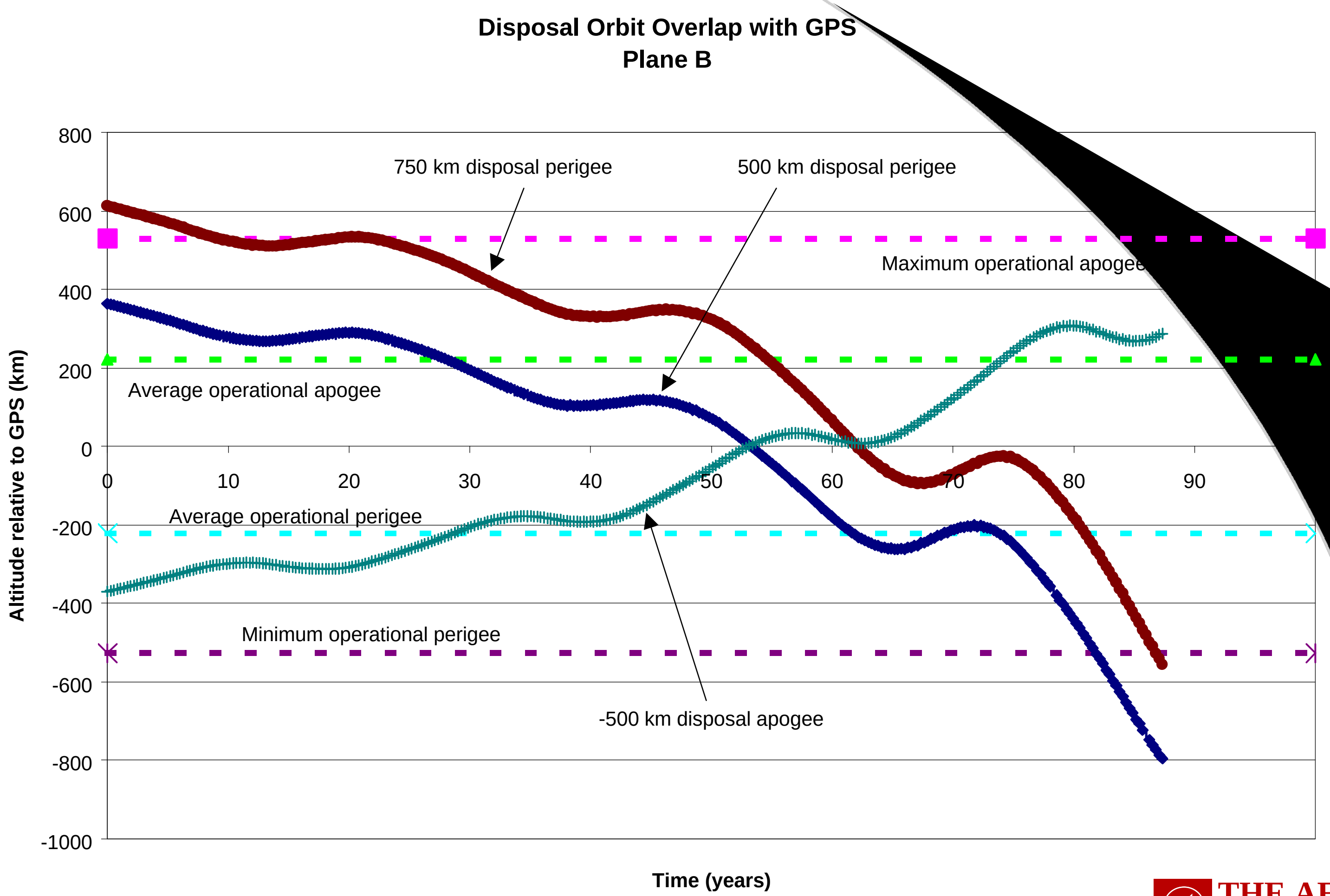
THE AEROSPACE CORPORATION

Collision Risk Analysis

- Assumptions
  - Operational GPS constellation has an orbital radius in the range 26559 +/- 530 KM
  - Disposed vehicles placed in orbits at least 500 KM from the operation orbit altitude
  - Four replacement launches per year
  - Each replacement launch places two objects in [illegible]al orbit: upper stage and decommissioned satellite
  - Replacements are uniformly random among orbit pla[illegible]
  - Operational vehicle eccentricities are constant over tim[illegible]
  - Risk for replacements is proportional to residence time
  - Analyzed three representative planes rather than actual s[illegible] planes
  - Assumed no collision avoidance maneuvering for operational vehicles

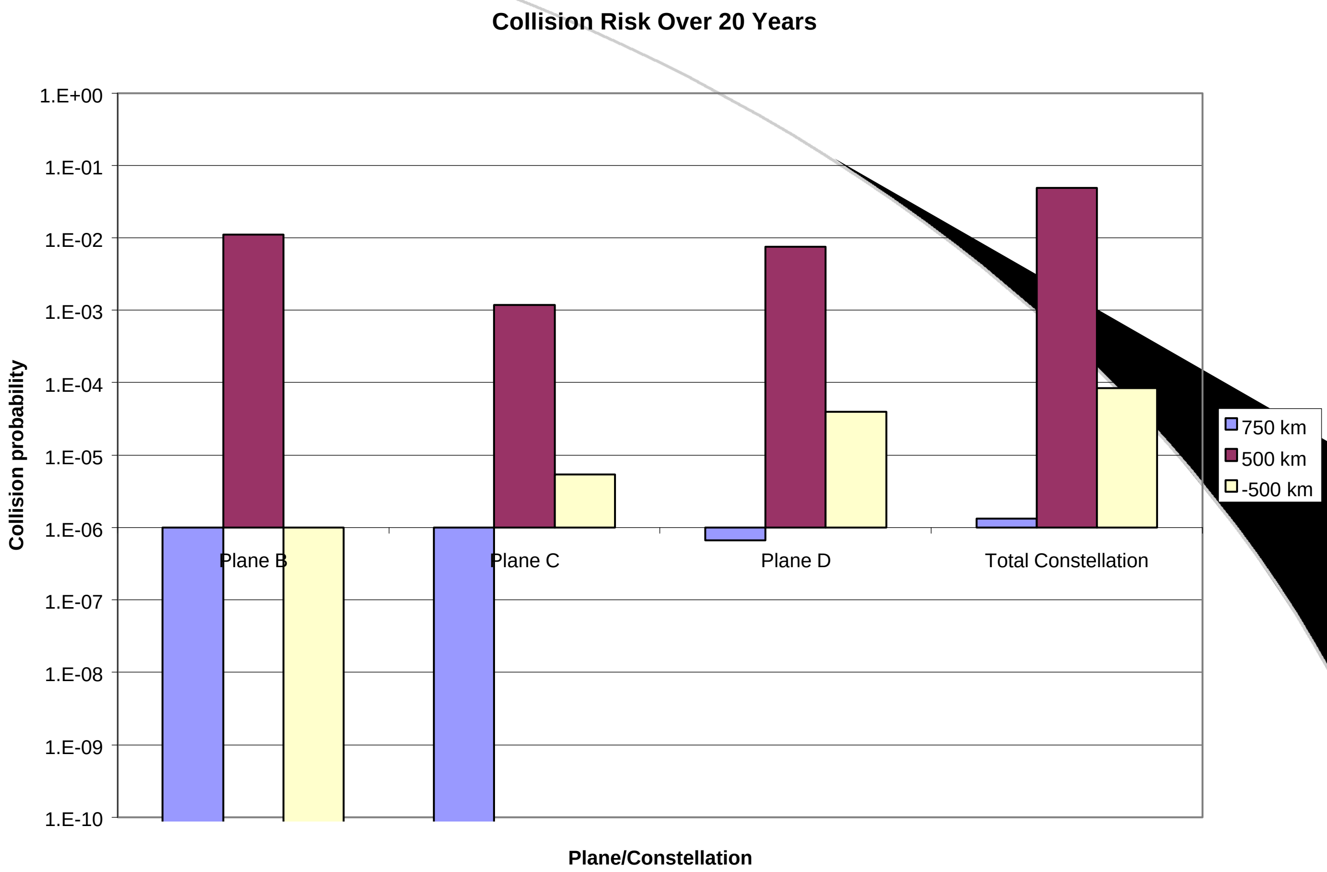
Disposal Orbit Overlap with Operational Constellation

- Eccentricity growth of 214 deg RAAN orbit plane yields constellation penetration within 20 years, and more significant penetration later



THE AEROSPACE CORPORATION

Collision Risk Over 20 Years



Altitude From GPS	Plane B (214 deg)	Plane C (274 deg)	Plane D (334 deg)	Total Constellation
750 km	0.00E+00	3.85E-14	6.61E-07	1.32E-06
500 km	1.10E-02	1.18E-03	7.46E-03	4.91E-02
-500 km	0.00E+00	5.45E-06	3.92E-05	8.39E-05

Preliminary Results of Collision Study

- Disposal orbits associated with all GPS operational orbit planes will eventually penetrate the operational constellation altitude range

- Using study assumptions, collision probability for disposed upper stages with the operational constellation is about 5%
  - ➢ assumes no eccentricity growth of operational satellites
  - ➢ assumes four replacement satellites per year

- Collision probability can be reduced from 5 X 10^{-2} to 1 X [illegible] by increasing the disposal orbit altitude from 500 KM to 75[illegible] KM

- GPS disposal orbit altitude may be significantly higher than 500 KM and would reduce the collision probability accordingly

Study Summary

- EELV performance is adequate for post mission disposal. Issues regarding disposal orbit injection accuracy as well as, vehicle and operational constraints need to be addressed.
- Recently discovered disposal orbit instability indicates that end-of-life disposal guidelines may be inadequate with respect to disposal orbit altitude.
- Long term collision hazard analysis between disposed vehicles and the operational constellation needs further analysis to determine acceptable disposal orbit altitude for both GPS satellites and EELV upper stages.
- Collision avoidance maneuvers might mitigate collision hazard.